INFLUENCE OF STATIC MIXER ON THE CROSS-FLOW MICROFILTRATION OF YEAST SUSPENSIONS

A. Jokić[1], B. Ikonić[1], Z. Zavargo[1], Z. Šereš[1], J. Gyura[1], C. Hodúr[2]
[1]University of Novi Sad, Faculty of Technology, Bul. cara Lazara 1, Novi Sad, Serbia
[2] University of Szeged, Faculty of Engineering, Mars tér 7., Szeged, Hungaria

ABSTRACT

This work studies the influence of operating factors on the microfiltration of baker's yeast (Saccharomyces cerevisiae) in presence of static mixer as turbulence promoter. Microfiltration is typically used to remove particles in range 0.1–10 µm from a suspension. It is a pressure-driven process widely used in concentrating, purifying or separating suspended particles and macromolecules from solution. During cross-flow microfiltration process permeate flux decreases with time as the retained particles are accumulated on and within membrane surface area where they create additional resistance to permeate flow. External fouling of the membrane is the result of cell, cell fragments and rejected particles accumulation on the top of the membrane surface in the course of cake formation, while deposition of the macromolecules and small particles inside of the internal porous membrane structure results in internal fouling, which is often irreversible contrary to usually reversible external fouling.
Experimental work was done with three membranes (A, B and C) with pore size 200, 450 and 800 nm. The results of microfiltration experiments for each membrane were estimated by analyzing the permeate flux without static mixer; permeate flux with static mixer; permeate flux improvement; reduction of specific energy consumption. Experimental results suggest that even though membrane A has smallest pore size of 200 nm it has the best performance considering steady state flux and reduction of specific energy consumption.

1. INTRODUCTION

Microfiltration is typically used to remove particles in range 0.1 to 10 µm from a suspension. It is a pressure-driven process widely used in concentrating, purifying or separating suspended particles and macromolecules from solution. During cross-flow microfiltration process permeate flux decreases with time as the retained particles are accumulated on and within membrane surface area where they create additional resistance to permeate flow. External fouling of the membrane is the result of cell, cell fragments and rejected particles accumulation on the top of the membrane surface in the course of cake formation, while deposition of the macromolecules and small particles inside of the internal porous membrane structure results in internal fouling, which is often irreversible contrary to usually reversible external fouling.
Avoidance of membrane fouling is not possible but it can be limited by the applying a number of different techniques. In addition to increasing filtration rate avoidance of membrane fouling makes it easer to clean them. Some of these techniques include backflushing [1, 2, 3], gas sparging [4, 5], turbulence promoters or static mixers [6, 7] and many others. The use of turbulence promoters or inserts in the tubular membrane is one of the technique applying hydrodynamic methods in reducing permeate flux decrease i.e. controlling membrane fouling. Turbulence promoters or inserts have many shapes and sizes. There are static rods, Kenics static mixers, metal grills, spiral wire, cone shape inserts, disc and doughnut shape inserts. A number of studies has been conducted in order to investigate influence of turbulence

promoters on the permeate flux increase during filtration process. Krstic et al. [6, 8] investigated influence of Kenics static mixer on the skim milk microfiltration, and their results suggest significant permeate flux increase when static mixer were inserted in the membrane channel. This type of mixers was successfully applied for permeate flux enhancement during separation of non-sucrose compounds from sugar-beet syrup by ultrafiltration with ceramic membrane [9]. Gupta et al. [10] conducted a study of the employment of helical baffles in membrane filtration of baker's yeast and dodecane-water emulsion was through ceramic membrane. Helical baffles with a different number of turns per baffle length. The authors reported that under the operating conditions, the use of a helically wound baffle in a membrane managed to increase the permeate flux at the same hydraulic dissipated power and without any additional equipment such as pulsating pump or any backwashing system. In cross-flow microfiltration with tubular ceramic membranes, turbulence promoters are inserted into membrane channel where they generate turbulence which subsequently reduces membrane fouling by producing a helical flow pattern and generating secondary flow to hinder the formation of a particle layer above the membrane surface. Helical baffles are likely to perform better compared to rod inserts, implying that the helical vortices improve the mixing between the boundary layer on the surface of the membrane and the bulk fluid to a greater degree than by simply generating turbulent flow using cylindrical rod inserts [7].

2. MATERIALS AND EXPERIMENTS

Baker's yeast (Saccharomyces cerevisiae) was used to make the yeast suspensions for the experiments. These microorganisms were selected according to their well-defined granulometric properties and their potentials to chemically clean the membrane. Prior to each experiment suspensions were prepared by adding a given weight of commercially available dry baker's yeast (Alltech-Fermin, Senta, Serbia) in saline solution (8.5 gL^{-1} sodium chloride) and stirred for 25 minutes. The sodium chloride balance the osmotic pressure across the cell wall, which if omitted would result in cell rupture.

The experiments were carried out in a conventional cross-flow microfiltration unit (Figure 1.). The feed was circulated by a peristaltic pump (ISMATEC, Switzerland). During experiments, both permeate and retentate were recycled back to the suspension reservoir. The transmembrane pressure difference was adjusted by the regulation valve. The inlet and outlet pressures of the membrane module were measured by two pressure gauges. The average of these two pressure values gave the value of transmembrane pressure as the outside of the membrane is vented to the atmosphere. The membrane module used was a Membralox™ 1T1-70 module (SCT, Bazet, France). The single channel ceramic membrane used had a nominal pore size 200, 450 and 800 nm (TAMI Deutschland) with the length of 250 mm and inner/external diameter of 6/10 mm. The useful membrane surface was 4.33×10^{-3} m^2.

The permeate flux was calculated from the time needed to collect 10mL of permeate. All measurements in this study were carried out in triplicate and the results averaged. The reproducibility of these measurements were good, the deviation between parallel experiments were in the range of ±6%. All experiments were carried out at the room temperature (25 °C). Experimental work was done with three membranes (A, B and C) with pore size 200, 450 and 800 nm.

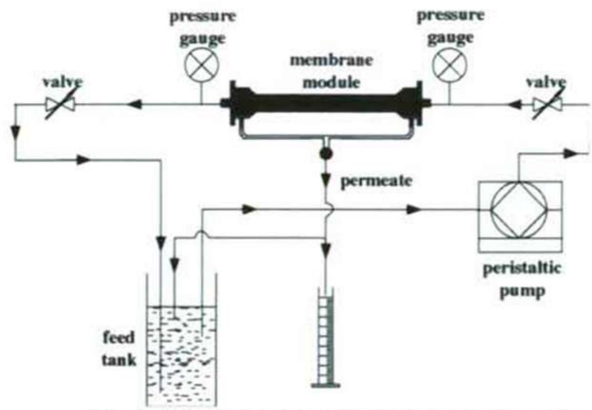

Fig. 1. Conventional cross-flow microfiltration unit

The static turbulence promoter used throughout experiments was the stainless steel Kenics static mixer. The static turbulence promoter was inserted inside the whole membrane tube and was fixed appropriately to avoid any movement due to the fluid flow. The Kenics static mixer used throughout experiments had 30 mixing elements with the diameter of 5 mm. It consists of a series of helical mixing elements made from thin, flat strips, twisted through 180° to form helices. Helices are turned around their main axis by 90° against the next element. Its characteristic geometric design produces the unique patterns of flow division and radial mixing simultaneously. Furthermore, the Kenics static mixer has "streamlined" shape which presents minimal surface area in the plane normal to the tube axis and prevents the creation of stagnation regions where impurities may collect and eventually foul the membrane. These features strongly favored the Kenics static mixer in respect to other commercial static mixers for cross-flow filtration applications [6].

2.1. Calculations

The efficiency of the static mixer as a turbulence promoter was determined as the improvement of permeation flux defined as [6]:

$$FI = \frac{J_{P,SM} - J_{P,NSM}}{J_{P,NSM}} \times 100$$

where FI, improvement of permeation flux (%); $J_{p,\ NSM}$, permeate flux without static mixer (L/m^{2}h); $J_{p,SM}$, permeate flux with static mixer (L/m^{2}h).

The efficiency of the static mixer as a turbulence promoter was also determined by reduction of specific energy consumption (ER). One of the most important parameter from an economical point of view is the specific energy consumption (E) defined as the power dissipated per unit volume of permeate [6]. The hydraulic dissipated power can be expressed as a product of feed flow rate and pressure drop along the module:

$$P = Q \cdot \Delta P$$

where P is the hydraulic dissipated power (W); Q feed flow rate (m^3/s); ΔP pressure drop (Pa). The specific energy consumption can be calculated as:

$$E = \frac{P}{J_P A}$$

where E specific energy consumption (kWh/m^3); J_P, the permeate flux (L/m^2h); A membrane surface (m^2). Reduction of specific energy consumption is defined as:

$$ER = \frac{E_{NSM} - E_{SM}}{E_{NSM}} \times 100$$

where ER, reduction of specific energy consumption (%); E_{NSM}, specific energy consumption without static mixer (kWh/m^3); E_{SM}, specific energy consumption with static mixer (kWh/m^3).

3. RESULTS AND DISCUSSION

3.1. Permeate flux without turbulence promoter

The first set of experiments was carried out to determine influence of membrane pore size on the permeate flux without turbulence promoter. The operating parameters were suspension concentration 6 g/L, transmembrane pressure 1 bar (10^5 Pa) and feed flow rate 130 L/h. Results of these experiments are shown in Figure 2.

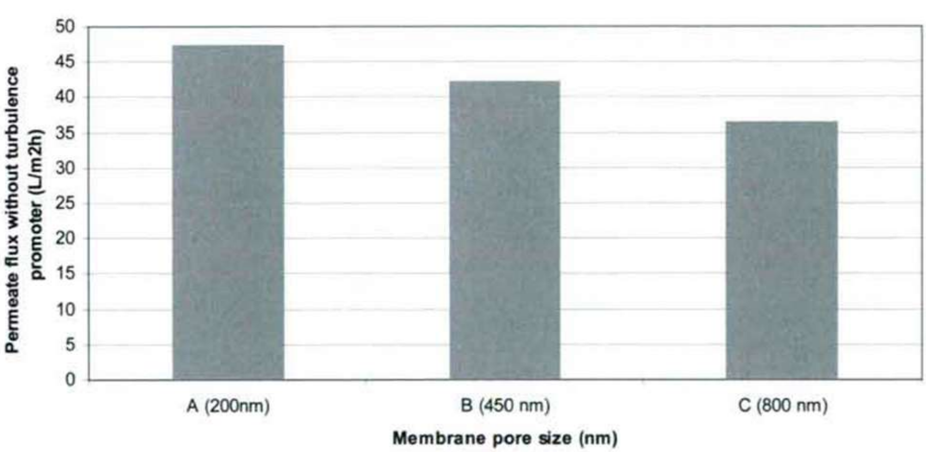

Fig. 2. Values of steady state permeate flux without turbulence promoter for different membrane pore sizes

As it can be seen permeate flux without turbulence promoter has the highest values for the membrane with the smallest pore size, in this case 200 nm. This behavior can be explained by fouling mechanism. One of the main characteristics important for microfiltration process is composition of filtration medium i.e. suspension. Components of suspension can influence microfiltration process directly or indirectly. Direct influence is fouling of membrane surface [11, 12], while indirect influence is manifested through modification of cell surface that can lead to changes in cell absorption to membrane surface [13].
During the experimentation process suspensions were made by adding predetermined quantity of dry baker yeast to the physiological solution. Suspension prepared in this manner, in addition to yeast cells have diluted cell material from the broken cells. This cell material consists from different types of sugars, proteins and etc. Particle size of this kind of materials is lesser when compared to the size of yeast cells. So, when these so called unwashed suspensions are filtered internal fouling can occur that can lead to the further steady state permeate flux decline. Internal fouling is particularly manifested when membranes with bigger pore size are used. Stopka et al. [14] reported that during microfiltration of beer similar results that permeate flux is smaller for membranes with pore size of 500 nm compared to flux when membrane with 200 nm pore size was used.

3.2. Permeate flux with turbulence promoter

The second set of experiments was carried out to determine influence of membrane pore size on the permeate flux with turbulence promoter. The operating parameters were the same as for experiments without static mixer (suspension concentration 6 g/L, transmembrane pressure 1 bar (10^5 Pa) and feed flow rate 130 L/h). Results of these experiments are shown in Figure 3.
By inserting turbulence promoter into membrane channel flow patterns inside channel are changed. Static mixers, in this study Kenics static mixer, characteristic geometric design produces the unique patterns of flow division and radial mixing simultaneously as well as its "streamlined" shape which presents minimal surface area in the plane normal to the tube axis and prevents the creation of stagnation regions where impurities may collect and eventually foul the membrane. This changes lead to decrease in cake formation i.e. the cake buildup at the membrane surface is hindered and in this is the reason for increase in permeate flux increase compared to the process without turbulence promoter. The positive effects of turbulence promoter are recorded for all three membranes used but the highest flux values were obtained for membrane with pore size 200 nm (membrane A).

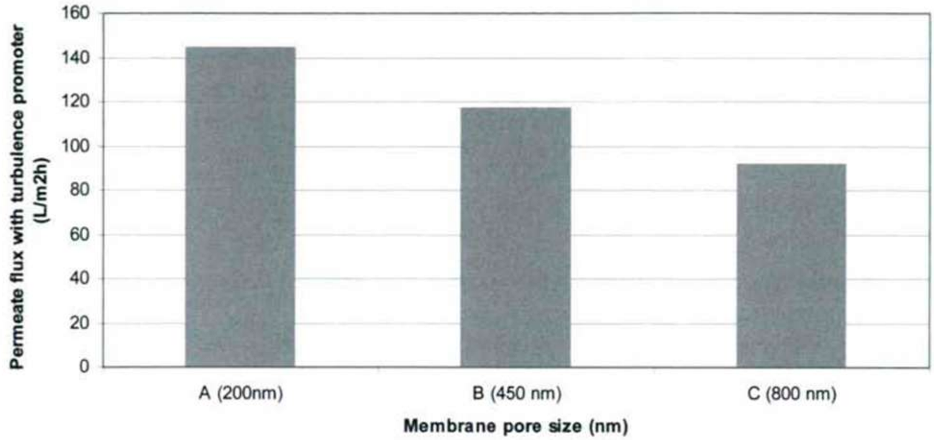

Fig. 3. Values of steady state permeate flux with turbulence promoter for different membrane pore sizes

3.3. Improvement of permeation flux

Improvement of permeation flux was calculated according to the given equation and the results are shown in Figure 3. As it was said earlier inserting the Kenics static mixer into membrane channel lead to the increase of permeate flux values for all selected membranes and this positive effect can be attributed to the increase in feed velocity, which resulted in less cake buildup and consequent less flux reduction.

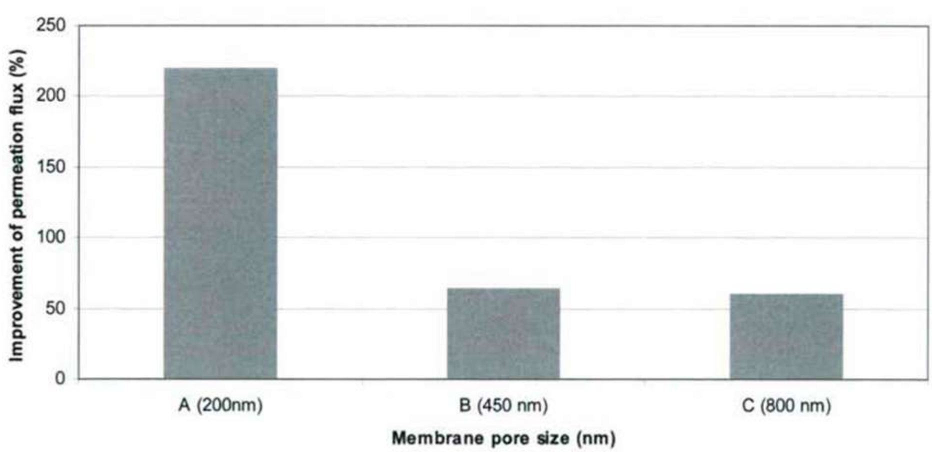

Fig. 3. Values of improvement of permeation flux for different membrane pore sizes

The results suggest that the biggest improvement of permeation flux was achieved for the membrane with the smallest pore size i.e. 200 nm. As it was said earlier during cross-flow microfiltration processes permeate flux decreases with time as the retained particles are accumulated on and within membrane surface area where they create additional resistance to permeate flow. External fouling of the membrane is the result of rejected particles accumulation on the top of the membrane surface in the course of cake formation, while deposition of the macromolecules and small particles inside of the internal porous membrane structure results in internal fouling. By inserting static mixer inside ceramic membrane flow patterns are changed and in this way external fouling is reduced. On the other side internal fouling is less influenced by static mixer [6, 8]. So the flux improvement is much more prominent for the membranes with smaller pore size as for them internal fouling is less manifested.

3.4. Reduction of specific energy consumption

Specific energy consumption is function of pressure drop along module and permeates flux achieved for specific experimental conditions and membrane surface area. By inserting turbulence promoter into membrane channel both of these variables are changed. Pressure drop along membrane is higher because of the increased resistance to feed flow, but on the other side permeate flux is increased due to the changes in fluid flow through membrane. In order to justify the use of static mixer from economical point of view reduction of specific energy consumption must be high as it is possible. That is achievable only in cases when increase in permeate flux is high enough to compensate for increase in energy usage needed for feed flow with turbulence promoter, i.e. increase in pressure drop along membrane channel. This is the reason why information about improvement of permeation flux can be to some extent ambiguous, since flux is always higher when turbulence promoter is used.
Reduction of specific energy consumption was calculated according to the given equation and the results are shown in Figure 4. It represents one of the most important parameter from an economical point of view. As it can be seen from Figure 4. the reduction of specific energy consumption has highest values for membrane A (200 nm). Similar results were reported for the microfiltration of skim milk [14].

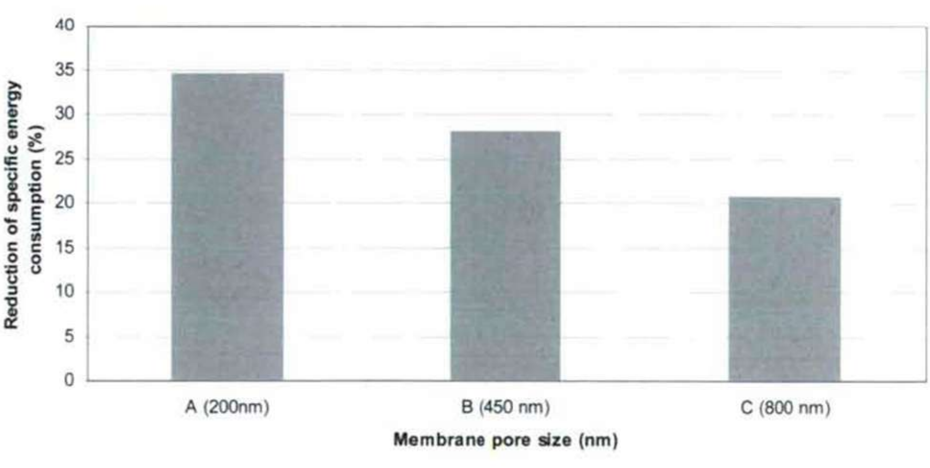

Fig. 4. Values of reduction of specific energy consumption for different membrane pore sizes

4. CONCLUSION

The results of this study illustrate the importance of proper membrane selection for microfiltration processes. The application of Kenics static mixer has positive effects on microfiltration of baker's yeast (Saccharomyces cerevisiae), i.e. permeate flux increases when static mixer is inserted into membrane channel. When the turbulence promoter is inserted fluid flow pattern are changed. This increased scouring of the membrane surface lead to decrease in cake layer thickness resulting in increased flux values. Experimental results suggest that even though membrane A has smallest pore size of 200 nm it has the best performance considering steady state flux value as well as reduction of specific energy consumption.

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REFERENCES

1. Serra C., Durand-Bourlier L., and Clifton M.J. , 1999. Use of air sparging to improve backwash efficiency in hollow-fiber modules, *Journal of Membrane Science*, 161 (1999) 95–113.
2. Srijaroonrat P., Julien E., and Aurelle Y., 2000. Unstable secondary oil/water emulsion treatment using ultrafiltration: fouling control by backflushing, *Journal of Membrane Science*, 159 (2000) 11–20.
3. Mores W.D., Bowman C.N., and Davies R.H., 2000., Theoretical and experimental flux maximization by optimization of backpulsing, *Journal of Membrane Science*, 165 (2000) 225–236.
4. Cui, Z. F., and Wright, K. I. T. 1996. Flux enhancements with gas sparging in downwards crossflow ultrafiltration: performance and mechanism. *Journal of Membrane Science*, 117(1-2): 109-116.
5. Bellara, S. R., Cui, Z. F., and Pepper, D. S. 1996. Gas sparging to enhance permeate flux in ultrafiltration using hollow fibre membranes. *Journal of Membrane Science*, 121(2): 175-184.
6. Krstić, D. M., Tekić, M. N., Carić, M. D., and Milanović, S. D. 2004. Static turbulence promoter in cross-flow microfiltration of skim milk. *Desalination*, 163(1-3): 297-309.
7. Ahmad, A., Mariadas, A., and Lau, K. 2005. Flux Enhancement by Introducing Turbulence Effect for Microfiltration of Saccharomyces cerevisiae. *Separation Science & Technology*, 40(6): 1213-1225.
8. Krstić, D. M., Tekić, M. N., Carić, M. D., and Milanović, S. D. 2002. The effect of turbulence promoter on cross-flow microfiltration of skim milk. *Journal of Membrane Science*, 208(1-2): 303-314.
9. Šereš, Z., Gyura, J., Djurić, M., Vatai, G., and Jokić, A. 2010. Separation of non-sucrose compounds from sugar-beet syrup by ultrafiltration with ceramic membrane containing static mixer. *Desalination*, 250(1): 136-143

10. Gupta, B. B., Howell, J. A., Wu, D., and Field, R. W. 1995. A helical baffle for cross-flow microfiltration. *Journal of Membrane Science*, 102: 31-42.

11. Kroner, K. H., and Kula, M.-R. 1984. On-line measurement of extracellular enzymes during fermentation by using membrane techniques. *Analytica Chimica Acta*, 163: 3-15

12. Russotti, G., Osawa, A. E., Sitrin, R. D., Buckland, B. C., Adams, W. R., and Lee, S. S. 1995. Pilot-scale harvest of recombinant yeast employing microfiltration: a case study. *Journal of Biotechnology*, 42(3): 235-246

13. Fletcher, M., and Pringle, J. H. 1985. The effect of surface free energy and medium surface tension on bacterial attachment to solid surfaces. *Journal of Colloid and Interface Science*, 104(1): 5-14.

14. Krstić D.: Poboljšanje „cross-flow" mikrofiltracije upotrebom statičkog mešača kao promotora turbulencije, doktorska disertacija, (2003) Tehnolški fakultet, Novi Sad, Srbija. (in Serbian).